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McLAREN GOLD-SILVER TAILINGS PROJECT

Park County, Montana

FEASIBILITY STUDY

July 31, 1988

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Granada Exploration Corporation

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SUMMARY AND CONCLUSIONS

The McLaren deposit consists of 247,000 tons of finely ground
pyritic tailings grading 0.100 ounces of gold per ton, 0.35
oz/t silver and 0.35% copper. The material leaches extremely
well, with about 80% gold recovery. It consumes 40 lbs. of
lime per ton and 6-7 lbs. of cyanide.

An agitated-vat-leach carbon-in-pulp plant is recommended and
its capital costs estimated at U.S. $4 per ton, of which $1
is salvageable; cash operating costs are estimated at $14.30
per ton. Rate of 400 tons per day, 9 operating months per
year is suggested. Project life will be 2.3 years. The
project is subject to various royalties and agreements.

One scenario is as follows:

Estimated Project Life Economics (US$1000's unless stated)

Capital cost		($1,001)
Working capital		(340)
Total preproduction		(1,341)
Gold sales (ounces)	19,300	
estimated selling price ($/oz)	$450	
gross sales less 1.5% refining		8,555
BP royalty at 10% NSR		(855)
Operating costs at $183/oz		(3,532)
Recover initial working capital		340
Recover salvage plant/equipment		300
Project operating profit		3,466
Less 1-yr interest @ 10%	(134)	3,332
Distribution to Camjac @ 20%		666
Distribution to Operator, 80% + int.		2,800

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Arithmetic sensitivity indicates that if gold sales average
$500, the project operating profit would increase from
$3,466,000 to $4,322,000; and if in addition costs can be cut
from $183 to $150 per ounce of gold then project operating
profit is projected at $4,959,000.

In our opinion the project will be feasible if operated in an
entrepreneurial manner with emphasis on keeping costs down.

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* * *

INTRODUCTION

Scope. This study has been prepared in house by Granada
Exploration Corporation. Specific characteristics of the site
(location, environmental) and material (quantity, grade,
metallurgy) are considered. Sizes, quantities and costs of
elements such as equipment, power, water, reagents and
engineering are estimated on the basis of other operations or
assembled from general industry experience. This study does
not constitute a final design.

Property Location. Park County, south-central Montana,
contiguous with the east edge of Cooke City; elevation 7,500
feet above sea level.

Access. Highway through Yellowstone National Park from
Livingston, Montana, 110 miles; Livingston is a rail terminal.

Ownership and Title. Land is about 40 acres held in fee simple
within U.S. Forest Service's Gallatin National Forest, in
Section 25, T 9 S, R 14 E, Park County, Montana. These are
patented mill sites and placer claims Idabelle, Copper Glance,
Horse Shoe and Greeley, Ore Cache, Grubstake and Fairview,
collectively known as the McLaren Tailings Property.

Owner is Camjac, Inc., a Montana corporation having no other
business activity, with offices in Great Falls. Title to the
property is not encumbered. Records verified in County Seat by
Granada. Camjac holds a title insurance policy and has a
complete abstract.

Granada holds an option to lease and extract minerals from the
property subject to certain conditions. There is no other
connection between Granada and Camjac.

Royalties. 10 percent net smelter return royalty retained by
Kennecott, a former owner, re-organized as BP Minerals America,
Inc. in 1987. (See following section.)

Twenty percent of net operating profits (i.e. before taxes on
income), after recovery of pre-production costs, payable to
Camjac. Granada may purchase some Camjac shares from current
stockholders.

Environmental Considerations. The tailings are currently
polluting Soda Butte Creek, which flows about 3 miles before
entering Yellowstone National Park. The pyrite contained in
the tailings is oxidizing and releasing 75 tons per year of

reddish-brown iron oxide waste. Fish cannot survive downstream.

The U.S. Park Service wishes the tailings cleaned up or relocated. The U.S. Environmental Protection Agency's Emergency Response Branch considered initiating this during part of 1987 and 1988 but has now changed its priorities for the immediate future (see Appendix).

Under the U.S. Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), any past owner is a "Responsible Party" in the event of a government-ordered cleanup, and may be deemed liable for all of the costs.

The long-term legal exposure to the present situation and to the effects of what a new operator might do is of more concern to BP Minerals than the potential gain from a royalty. Accordingly BP has recommended to Granada that final tailings disposal be at a permanent location outside the Soda Butte Creek drainage, about 2 miles from the present site, and Granada has asked BP to reinvest proceeds of their royalty into funding such a plan if it is drawn up. This matter is pending.

Mine and Mill History. The McLaren mine is located 3 miles north of the old mill site. It operated from the 1930s to about 1951 for copper, with by-product gold and silver. During World War II it was not affected by Executive Order L-208 which closed gold mines. Ore was trucked down from the mine during the summer and the mill operated nearly year-round.

The McLaren mine is not part of this venture.

SUPPLEMENTARY MATERIAL

The following exhibits are appended and are part of this study:

1. Map of Property Location

2. Map of Property Area, topographic, scale 1:24,000

3. Kennecott, table of analyses, general map of tailings and map of 1965 auger holes, 3 pages;

4. State of Montana, analyses and map of 1975 test wells which were assayed, 2 pages;

5. Granada, assays, map of 1987 backhoe holes, sulfate and acid-soluble copper analyses, contour map of thickness, ore

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reserves calculation table, 7 p.;

6. McClelland Laboratories, Inc., March 1988 report, 19 p.;

7. Russell M. Honea, May 1988 report, 9 pages;

8. Lou M. Cope, P.E., January 1988 economic study, 3 pages;

9. E.P.A. letter, May 27, 1988, 1 page;

10. Granada letter to BP, May 31, 1988, 1 page;

11. Article "Heap Leaching in California" from "California Geology," a State periodical, which is a succinct description of the overall process of heap and vat leaching with cyanide, 8 pages.

WORK COMPLETED

Previous Work. Sampling programs for which records are available:

1. Kennecott, 1965, 47 auger holes to base of deposit, fire assays on gold and silver, analyses for copper;

2. State of Montana, 1975, many test wells of which 9 were sampled for analysis by atomic absorption (AA).

The State and EPA have drilled and cased numerous additional wells at various times for monitoring the water table, water quality and acid discharge.

Prior metallurgical tests were performed by labs on behalf of others and were reviewed but not included in this report. They are: 1981 tests by Orval H. Hilliard, P.E.; 1981 tests by Spectre Engineering of Spokane; 1981 tests by Louis W. Cope, P.E., of Denver; reference to but no data on 1983 tests by Larry C. Hoffman, P.E., in a report; and 1985 tests by R.O. Huch of Kerley Mining Products, Inc., of Sahuarita, Arizona.

Current Work. Granada Exploration, October 1987, dug 8 backhoe holes to 13 feet. 47 samples were taken continuously down 1.5 or 2 foot intervals assayed for gold and silver. A 500-lb. composite sample was taken for metallurgical tests.

Assays were performed by Chemex Labs Ltd., North Vancouver, B.C. Standard methods were used: gold was run by fire assay using half-assay tons, finished by AA; silver by aqua regia

digestion and AA.

Independent labs and consultants were retained for metal-
lurgical tests, petrographic tests and preliminary design
considerations.

On the basis of all of the above Granada has calculated
reserves, selected the process, determined its feasibility, and
outlined further work requirements.

Camjac, in necessary actions with the State of Montana,
defended its rights to 224 gallons per minute (1/2 cfs) year
round on Soda Butte Creek, with minor assistance from Granada.

TECHNICAL DESCRIPTION

Physical. The tailings are layers of very finely ground sand
containing pyrite and precious metals. Color is deep chocolate
when wet, dusty buff when dry.

The undisturbed material is gummy, low-permeability stuff, dry
only in the upper few feet. The tailings are not as highly
oxidized as deposits in desert environments. Considerable
information on ground water movement and chemistry has been
collected by the environmental agencies.

Particle size distribution is a bell-shaped curve with only
2.5% greater than 35 mesh, a median at 250 mesh, and about 38%
passing 325 mesh (respective sizes are about 0.4 mm, 65
microns, and 45 microns).

Mineralogy. Gold occurs mainly as free gold with some micron-
sized grains encapsulated in sulfides. Sulfides are mainly
pyrite with lesser amounts of chalcopyrite and traces of
chalcocite and covellite. Gangue minerals are mainly
silicates. Although the material appears to have the
consistency of clay, clay minerals are nearly absent.

Size and Shape. The deposit is 800 feet long and 500 feet
wide, and lies on top of glacial gravel deposits. Its
thickness varies from 35 feet on its southwestern edge to zero
feet on its north-eastern edge, averaging about 17 feet. This
represents 247,000 dry tons of tailings.

In the 1960s Kennecott stabilized the surface of the tailings
by bulldozing and leveling about 1.5 to 3 feet of gravel over
the top.

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Grade. Weighted averages of the three systematic sampling programs follow:

	Gold (oz/t)	Silver (oz/t)	Copper (%)
Kennecott	0.103	0.324	0.39
State of Montana	0.106	0.357	0.313
Granada	0.096	0.44	--
Granada's recalculated			
Kennecott	0.099	0.329	--

Ore Reserves. Calculations -- weighted averages of polygons of Kennecott holes, checked by polygons of Granada holes. The former is included in the appendix. (The computer print displays the data and results but not the integration.)

Volume -- horizontal dimensions are visible; vertical were measured in Kennecott's holes, numerous State wells and checked by Granada's holes. Total volume of blocks is 4,200,000 cubic feet.

Density -- assumed previously to be 20 cubic feet per ton (thus 210,000 tons calculated). Granada measured in-place dry density (by volume of undisturbed sample, excavated, dried and weighed) at 17 cubic feet per ton.

Tonnage -- Actual calculation was by blocks; overall 4,200,000 cubic feet/17 = 247,000 tons.

Assays Selected -- From the weighted averages above the following are selected for planning purposes: 0.100 ounces of gold per ton; 0.35 ounces of silver per ton; less importantly 0.35 percent copper (7 lbs. per ton).

Total contained metal -- 24,700 ounces of gold; 86,000 ounces of silver; 1.7 million pounds of copper. No allowance is made for dilution. "Ore reserves" does not imply any particular metallurgical recovery.

Level of Confidence -- Ore reserves lie in the proven or measured class. These figures are believed correct within the 95% confidence level.

Metallurgy. McClelland Laboratories, Inc., Sparks, Nevada, performed bottle-roll, agglomerating, and column-leach tests.

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Their report indicates the following:

1. material leaches well -- recovery of gold by bottle roll and by column leach tests is 75-80 percent;

2. optimal pellet requires very little cement and 30-40 lbs. of lime to agglomerate;

3. pH control in column requires about 40 lbs. of cement and 40 lbs. of lime per ton of material, a total of 80 lbs. of base;

4. cyanide consumption is 6-7 lbs. per ton of material.

These tests were more comprehensive than prior tests. The results are generally consistent with prior tests.

Mineralogy. Dr. Russell M. Honea investigated the mineralogy for the purpose of investigating the high reagent consumption. He reported that free gold is present as liberated grains up to 30 microns in size, with some very small grains (less than 5 microns) encapsulated mainly in pyrite or silicate grains.

Consumption of base (CaO, NaOH, cement) is likely caused by minor gypsum and jarosite (calcium and iron sulfate respectively) and the cyanide consumption by minor chalcocite and covellite (copper sulfides that are oxidation products).

Oxidation. Composites were made to further study distribution and quantity of undesirable minerals. In the test holes, the top 1 to 2 feet of the deposit and some thin permeable zones are stained rusty orange -- apparently partly oxidized to jarosite (iron sulfate).

Analyses of composite samples (see appendix) suggest that the only apparent difference between "oxide" and "sulfide" zones is that copper is leached from the oxidized material. The "oxide composite" reports 0.16% total Cu and 0.01% acid soluble Cu; the "sulfide zone" averages 0.35% total Cu and 0.05% acid soluble.

Sulfate/sulfide ratios and quantities do not seem to differ between zones. About 2 to 5% SO_4 and 11 to 17% S as sulfide are present throughout.

DESIGN CONSIDERATIONS

Site-Specific Aspects. Reagents and materials will be trucked
through Yellowstone National Park. The U.S. Park Service is the
principal agency desiring the clean up of the McLaren tailings
and approval is expected.

An operating season of 9 months is projected. Cold weather and
frozen water supply and tailings systems will be more serious
in effects than snow.

Sound environmental practice will require protecting the Soda
Butte Creek drainage from accidental discharges in excess of
those permitted.

Location contiguous to Cooke City eliminates the need for some
housing, service and supply arrangements.

Power is supplied to Cooke City from Pacific Power & Light and
may be available at reasonable cost.

Mining Method. Excavation will not be a major cost item.
Equipment will be one medium loader.

Overlying gravel will be stripped, stockpiled and replaced.
Some wood, roots and junk are expected at the base.

Processing Method. Conventional agitated vat leach carbon in
pulp plant will be used as indicated on the following page.

Preliminary design capacity of the plant is 400 tons per day.
Some major equipment has been sized. Insofar as possible most
will be acquired used.

Plant will be located near the tailings deposit; preliminary
location at point "B" on the Area Map (Appendix 2).

Tailings Disposal. Preliminary design calls for thickening
near the plant and disposal into a lined tailings pond at point
"C" on the Area Map (Appendix 2).

BP Minerals has recommended disposal at a permanent site
outside the Soda Butte Creek drainage at point "D" at or near
Colter Pass.

GENERALIZED FLOW SHEET
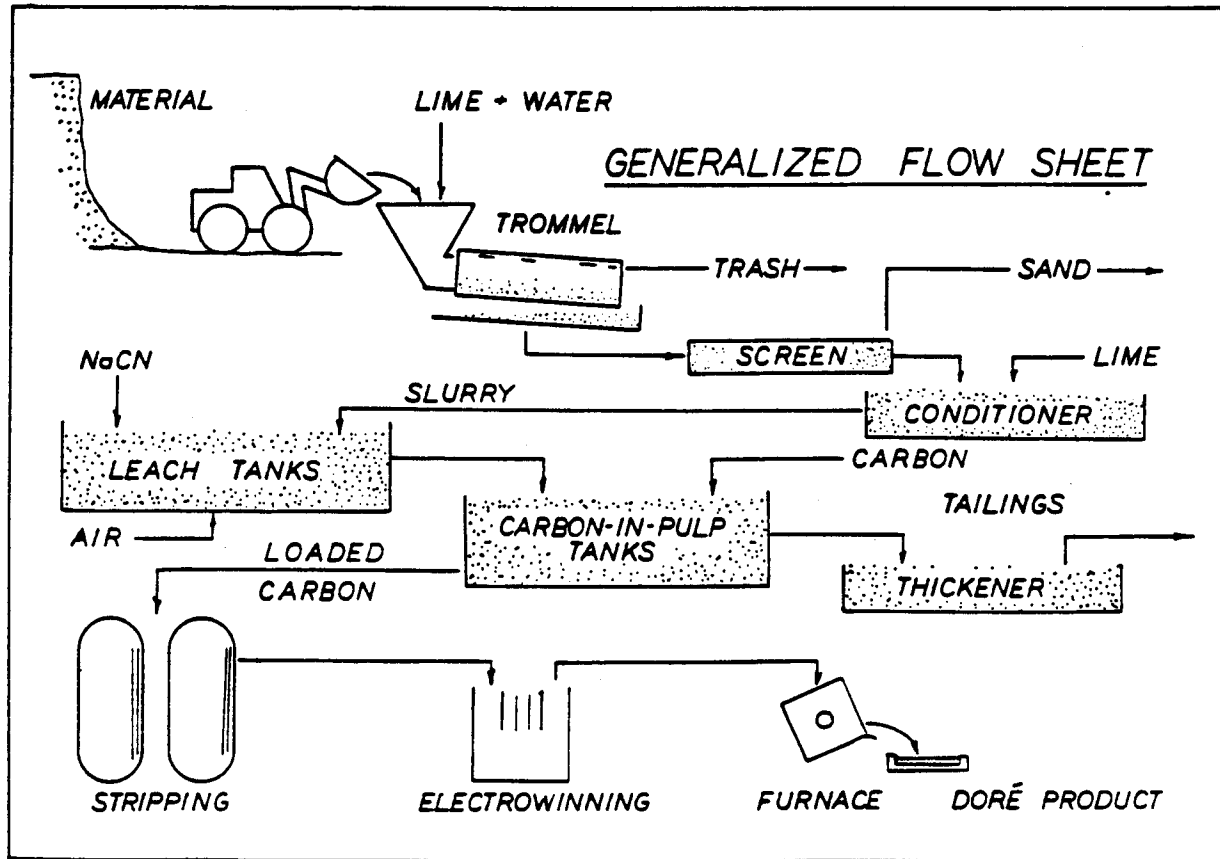
Transport would be about 2 miles, probably by truck. This would require lease, purchase or trading of public land administered by the U.S. Forest Service, and permitting by the Forest Service, or purchase of land from private interests. About 10 acres would be required. Details have not been worked out.

This would be commercially feasible if the extra cost could be charged to BP Minerals' royalty. The cost estimates in the following sections assume no extra tailings disposal cost.

Alternate or Additional Processes. Bacterial leaching is under consideration as a method for oxidizing the cyanide-consuming copper and consequently cutting reagent costs and recovering a marketable copper product. Bacterial leaching is a standard

technology which uses the naturally occurring <u>Thiobacillus</u> <u>ferrooxidans</u> in an acid environment to augment the oxidation of sulfide minerals.

The concept would be to use <u>T. ferrooxidans</u> to (a) <u>in-situ</u> leach wind-rowed material or (b) vat-leach the pulp, strip out whatever copper is readily soluble and recover it with iron filings, then wash and neutralize the pulp, then condition the pulp for the gold-recovery circuit. This could be worthwhile if base consumption and cyanide consumption are significantly reduced.

Agglomerated heap leaching was tested and shelved for reasons of the gummy nature of the material, the high reagent consumption, and the consequent lack of confidence in ability to control the process metallurgy.

Gravity and flotation were rejected as non-economic based on the obvious properties of the material and the poor results obtained by prior workers.

COST ESTIMATES

<u>Capital</u>. Referring to the table (COSTCAPT) on the following page, the preproduction capital cost is estimated at approximately U.S.$870,000. An additional 15% or $131,000 is allocated for delays or cost overruns for a total of $1,001,000.

Sensitive items are reasonable elapsed permitting time (3 to 5 months, during which time certain project activities can be carried forward), without stalls or undue delays; confirmation of leach residence time at 24 to 36 hours and total leach and CIP tank capacity at a total of approximately 40,000 cubic feet; overall skill of project manager to canvas the region and buy quality equipment at used prices; and ability to minimize trucking and installation costs.

Tailings pond is single-lined and installed at 50% of capacity initially, with remainder charged to operating costs.

The conceptual capacity is 400 tons per day. Estimated cost would be reduced for a 200 or 250 tpd capacity, although not proportionately.

A copper circuit is not included in this estimate, nor is the cost of installing tailings disposal systems outside the Soda

GRANADA EXPLORATION CORP., McLAREN PROJECT, PARK COUNTY, MONTANA
Processing Plant Cost Estimate, June 1988, File: COSTCAPT

Item	Unit(s)	UnitCost	Cost in US$	Subtotals
DETAILED DESIGN AND ENGINEERING COSTS				
Final design and engineering			$10,000	
Travel/clerical/estimating			15,000	
Environmental protection			10,000	
Consultants/legal			10,000	$45,000
ACQUISITIONS				
Acquire USFS land adjacent	stake M.S. claims	3,000	3,000	3,000
EQUIPMENT AND INSTALLATIONS				
Water supply tank	30,000 US gal		3,000	
Pipeline, installed	3"x1200'PVC	$5.00	6,000	
Trommel and motor		used price	25,000	
Belt/feeder/screens/pumps		used	14,500	
Precondition tank		used/make	18,750	
3 air tanks, total 7,000 cu ft	available	scrap price	6,000	
6 air tanks, total 15,000 cu ft		used/make	112,500	
CIP tanks, 18,000 cu ft		used/make	135,000	
Compressors			5,000	
Tanks/sumps/makeup/water/lime			4,000	
Carbon screens/tanks			5,500	
Feeders/elec/pipe/valves			30,000	
Strip/electrolyt/furnace			20,000	
Electric hookup	1/4 mile	est.	5,000	
Trailers/pole buildings			30,000	
AA unit/sample prep equip			12,000	
Freight allocated to plant			14,000	
Earth/civil works allocated			10,000	
Engineering/labour allocated			30,000	
Purchasing/travel/tel alloc			5,000	492,050
MOBILE EQUIPMENT (buy used/alternately lease)				
1 three-yd rubber-tired loader			70,000	
1 ten-ton dump truck			8,000	
1 20-ton highway truck/trailer			60,000	
3 light pickup trucks			30,000	
1 fork lift			7,500	
1 crane truck			5,000	
shop equip/tools/spares/misc			10,000	190,500
TAILINGS, THICKENER & HOLDING SYSTEM				
Cutting timber/disposing of slash			0	
Thickener/pipe/pumps			85,000	
Earthwork, initial pond	25,000 tons	$0.50	12,500	
Liner, initial pond	85,000 sq ft	0.50	42,500	140,000
Total all items				$870,550
Contingency for delays or overruns		15%		130,583
Total all costs				$1,001,133

Butte Creek drainage.

As to financial considerations, the estimates include only purchase, not leasing of equipment, and are for physical costs only, without including interest or any purchases of Camjac stock.

Working capital is not included in this estimate. In a cash-flow estimate about two months working capital (or $340,000, see below) is added to pre-production costs.

Operating. Referring to the table on the following page (COSTOPT), the estimated operating cost is $14.28 per ton, $5,710 per day, or $183.03 per ounce of gold produced (where recovered silver provides a $14.74 per ounce credit to gold costs).

"Mining" is an independent charge of $0.75 per ton as if conducted by a contractor. It involves one person and one loader five shifts per week.

The most sensitive specific cost element is the cost of cyanide, lime and caustic soda, and the cost of trucking these to the project site. This is estimated at nearly $100 per ounce of gold produced.

That single element justifies continued efforts at its reduction (i.e. prior removal of some sulfate and copper).

Staff, excluding miner and trucker, is estimated at one manager and 4 rotating 2-man shifts. The manager is assumed to be employed year-round and the staff only for the 9-month operating season. No specific other provision is made for lab, bookkeeping, purchasing, selling, consulting, security, executive travel or off-site overheads.

The estimate is sensitive to costs of additional labor or additional reclamation if required.

The costs estimated are cash costs and do not include interest, royalties, hedging, or taxes other than severance taxes.

No similar estimate has been made of operating costs at a different rate of production.

The broad overriding consideration in an analysis of an operation at the McLaren is that it would be sensitive to over-engineering or over-managing. The size, grade and nature of

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GRANADA EXPLORATION CORP., McLAREN PROJECT, PARK COUNTY, MONTANA
Processing Plant Operating Cost Estimates, June 1988, File: COSTOPT

DESIGN PARAMETERS: 247k-tons, Open pit, Vat leach CIP plant
1. 400 tons per 24-hr day; excavate 1 shift per day; process 3 shifts per day
2. 9 months or 270 days per year; life 2.3 years
3. millheads 0.10 oz/ton gold, 78% recovery, 31.2 oz/day; 8,424 oz/yr
4. millheads 0.35 oz/ton silver with 60% recovery

Operating Cost Item	Unit(s)	PerTon	Calculated values in US$		
			PerOpDay	PerOzGold	PerOneYear
Mining/hauling: labour/fuel/maint.		$0.75	$300	$9.62	$81,000
Reagents -- NaCN	$0.70/lb.	4.90	1,960	62.82	529,200
-- CaO and NaOH	$0.06/lb.	2.40	960	30.77	259,200
-- carbon		0.20	80	2.56	21,600
Stationary electric power	$0.03/kwh	0.30	120	3.85	32,400
Other fuels/lubricants		0.10	40	1.28	10,800
Freight to/from Livingston, MT	110 ml/day	0.20	80	2.56	21,600
Manager salary	$48,000/yr	0.45	180	5.77	48,600
8 plant staff, avg.	$26,000/opyr	1.93	772	24.74	208,440
Statuatory benefits/insurance	30%	0.71	284	9.10	76,680
Add'l tailings disposal	$50,000	0.20	80	2.56	21,600
Treat tailings ProMac bactericide		0.08	32	1.03	8,640
Provide: reclaim tailings area	$50,000	0.20	80	2.56	21,600
Provide: reclaim mined area	100,000	0.40	160	5.13	43,200
Credit silver recovery	$5.50/oz	-1.15	(460)	-14.74	(124,200)
Montana severance tax	6%	2.11	842	27.00	227,448
Other					
Contingencies for unexpected events		0.50	200	6.41	54,000
Total costs per ton/day/ounce/year		$14.28	$5,710	$183.03	$1,541,808

Notes:
1. The capital and operating costs given in these tables are estimated for a base-
line case where only gold and silver are recovered. The costs and benefits of copper
copper is expected to produce a marketable product and to cut costs for the gold
recovery by reducing the lime (CaO), caustic soda (NaOH), and cyanide (NaCN) needs.
2. As engineering progresses a secure permanent tailings disposal site will be selected
about 2 miles away from the Soda Butte Creek valley and Granada will request that
BP Minerals American, Inc., pay the additional cost of hauling and depositing the
tailings at this site. Under the U.S. Comprehensive Environmental Response, Compensation
and Liability Act ("CERCLA") it will be in BP's best interest to do so and to fund this
work from the proceeds of their royalty. Preliminary discussions have been held
between Granada and BP on this subject.

the material require that it be operated by experienced people with management support for making decisions and adjustments at the site.

TIMETABLE

The following is assumed as the basis for the estimates: At 400 tons per day and 9 months per year operation the project will have a life of about 2.3 years. Permitting, design and construction will take place during late 1988 and the first part of 1989. Full production would be in 1989, 1990 and part of 1991. Final reclamation would start concurrent with operations and conclude in 1991.

REMAINING TASKS

The following work is recommended:

1. Testing of bacterial leaching, process design if successful;

2. Hire full-time engineer/metallurgist with instructions to design process and plant in enough detail to start permitting process;

3. Apply for permits and continue with that process;

4. Final design and sizing and costing of elements;

5. Start equipment purchases; complete permitting process; continue to work with BP in off-site tailings disposal concept.

The summary and conclusions of this study are given at the beginning.
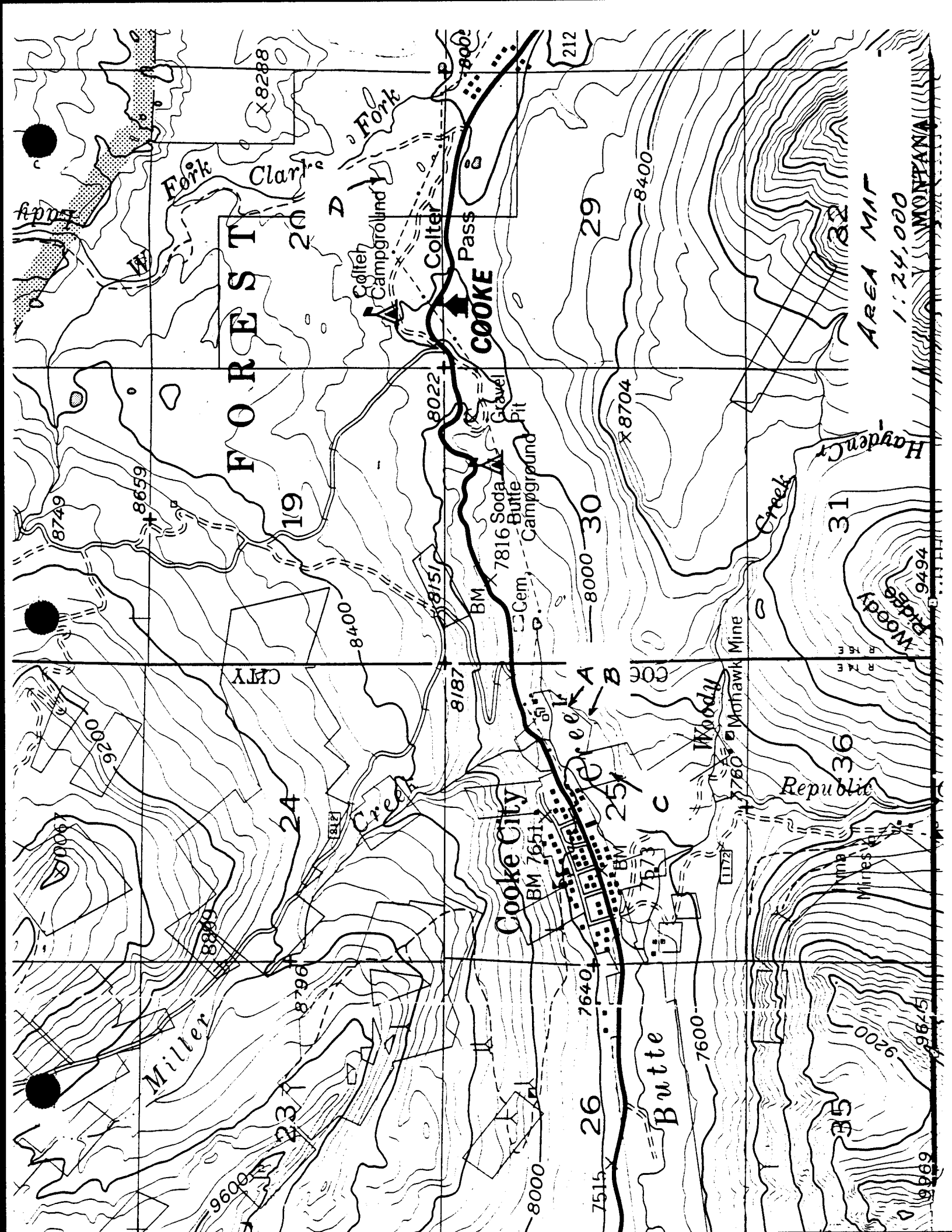
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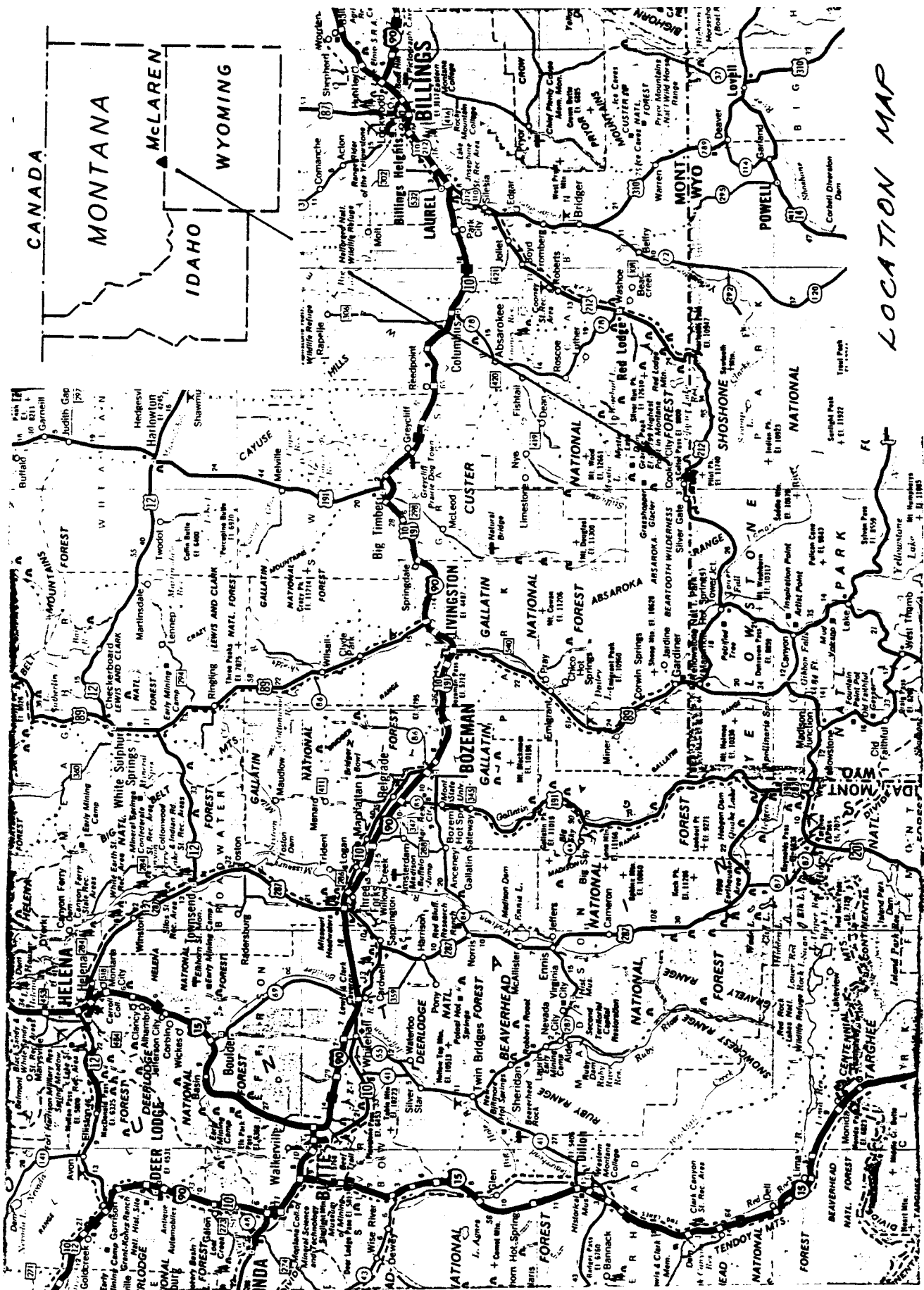
LOCATION MAP

FOREST

Clarks Fork

W Fork

Fork

D

Colter Campground

Colter Pass

COOKE

×8288

212

8400

29

32

MONTANA

AREA MAP

1:24,000

8022

Gravel Pit

8151

8704

19

BM

7816 Soda Butte Cem. Campground

8659

8749

Hayden Cr

30

8000

31

Woody Ridge

9494

BM 8187

CITY

A

B

Mohawk Mine

Woody Creek

36

Republic

9200

24

Creek

Cooke City

BM 7651

BM 7673

25

C

780

9669

9600

8800

Miller

23

26

Butte

35

7640

7600

7800

8000

7514

9645

9200

8000

9660

RIGHT-OF-WAY 250' EACH SIDE OF CENTER LINE OF HIGHWAY.

7704.9E

Butte Creek

Soda Butte Creek

°7683

Copper Glance
M.S. 10814 A

Copper Glance
M.S. 10814 B

Copper Glance No.2 M.S. 10814 B

Gravel

(Abandoned)

7644

78647

7041.4

7643.2

7654

UPPER DAM

7650

7642

7631

7627

7673

7647

7659

7636

Horseshoe B Greeley placer
4072

RIGHT-OF-WAY 50' EACH SIDE OF HIGHWAY

Ore Cache M.S. 53B'

TAILINGS AREA

Ioodelle B
M.S. 10815 B

7637

7637

7646

7630

7644
7651

7629

7603

7605

7664

7637

7624

7636

7631

7631

LOWER DAM

Gravel
"BORROW AREA"

7621

7813

7899

7604

Cooke City Townsite

7810

7801

7899

7892

Dark house

7807

MARTIN STREET

Block II

7591

78803

7598

78111R

7878

7873

Ioodelle A
10815

7872

7570

7568

7544

7259

7582

Block 12

BCMC LANDS

Diversion Channel

Area Restored

DIVERTED CHANNEL OF

Russell M. Honea
Consulting Geologist

AC 303 466-9719

<table>
<tr><td>Office
1105 BELLAIRE
BROOMFIELD, COLORADO 80020</td><td>Mailing Address
P.O BOX 323
BROOMFIELD, COLORADO 80020</td></tr>
</table>

May 24, 1988

Mr. Andrew E. Nevin
Granada Exploration Corp.
8 South Michigan Ave.
Chicago, Illinois 60603

Re: McLaren Mineralogy

Dear Mr. Nevin:

Enclosed are results of detailed optical examination of four polished
sections of the tailings sample forwarded by McClelland Laboratories.
Photomicrographs are included to illustrate some of the pertinent
mineralogic and textural characteristics.

Gold is present in the sample as liberated particles up to 40 microns
in diameter, and in smaller particles (3 to 5 microns) locked in
silicate gangue, chalcopyrite, and pyrite fragments. Associated with
the native gold are dominant pyrite along with lesser amounts of
chalcopyrite, sphalerite, pyrrhotite, bornite, enargite, arsenopyrite,
chalcocite, and covellite. Also present is an oxide suite that includes
magnetite, hematite, and goethite. The latter is an oxidation product
of sulfides. Jarosite, a potassium iron sulfate, is also present as
an oxidation product, and is almost certainly accompanied by small
amounts of other iron sulfate oxidation products.

Jarosite was also verified by X-ray powder diffraction techniques, and
is accompanied in powder diffraction patterns by gypsym-$CaSO_4 \cdot 2H_2O$ and
minor quartz.

Please let me know if there are questions or problems regarding the
data.

Sincerely,

Russell M. Honea

Encl.

MLI-1103. Liberated and locked or encapsulated native gold particles with dominant pyrite and lesser amounts of chalcopyrite-sphalerite-pyrrhotite-bornite-enargite-chalcocite-covellite plus an oxide suite of magnetite-hematite-goethite in partially oxidized tails with jarosite*

Native gold - -1% - Golden yellow and with color suggesting relatively low silver content, isotropic but does not show complete extinction because of polishing scratches, low hardness and is moderately well polished. Occurs variously as small (22, 30, 39 and 40 microns) liberated particles and as even smaller grains locked in pyrite (4 microns), chalcopyrite (3 microns), and quartz gangue (5 microns). One of the liberated grains is bordered in part by enargite.

Pyrite - 31% - Pale yellow, either isotropic or with weak anomalous anisotropism and very faint polarization colors of blue to purplish, hard and is well polished. Is the dominant sulfide and present very largely as liberated fragments. Some shows oxidative corrosion at grain margins. At times forms composites with or encloses minor amounts of chalcopyrite and sphalerite - and traces of pyrrhotite and bornite.

Chalcopyrite - 1% - Bright yellow and with slight greenish tint in polished surface, weakly anisotropic and with faint polarization colors of blue to green, moderate hardness and is well polished. Present as liberated grains, as composites with and locked by pyrite, and as scarce composites with magnetite-hematite. Some of grains are rimmed by chalcocite and covellite. Also rarely as inclusions in sphalerite.

Sphalerite - -1% - Medium gray, isotropic and with poorly developed brown internal reflections, moderate hardness and is well polished. Occurs as relativley scarce liberated particles and as grains forming composites with or locked by pyrite fragments. Sometimes contains microscopic blebs of chalcopyrite.

Pyrrhotite - -1% - Light creamy brown, strongly anisotropic and with polarization colors of yellowish green to reddish brown, moderate

hardness and is well polished. Observed in very small amount as microscopic inclusions in pyrite fragments.

Bornite - -1% - Pinkish brown color, very weakly anisotropic but without distinctive polarization colors, moderate hardness and is well polished. Present in minor amount with chalcopyrite as micron-sized inclusions in some of pyrite fragments.

Enargite - -1% - Light gray with pinkish brown tint, strongly anisotropic and with polarization colors of green to orange red, moderate hardness and is well polished. Occurs as small subhedral prismatic inclusions in pyrite and in one instance bordering native gold particle.

Chalcocite - -1% - Light gray and with bluish tint, anisotropic but without distinctive polarization colors, low hardness and is well polished. Present in small amount either alone or with covellite rimming and replacing chalcopyrite - and rarely as rims on pyrite. Is formed as a product of secondary enrichment.

Covellite - -1% - Light to dark blue due to strong bireflectance, extreme anisotropism and with polarization colors of orange to red, low hardness and is well polished. Occurs in minor amount either alone or with chalcocite rimming and replacing both chalcopyrite and pyrite. Is also formed as a secondary enrichment product.

Magnetite - 3% - Light brownish gray, isotropic, hard and is well polished. Occurs both alone and more commonly with hematite as liberated fragments. Rarely encloses or forms composites with chalcopyrite. Most of grains show variable weak to strong replacement by hematite.

Hematite - 2% - Light gray with slight bluish tint, moderately anisotropic and with polarization in shades of gray, hard and is well polished. Present in small amount as

MLI-1103.

platy crystal aggregates (specularite) and more commonly as partial to essentially complete replacement of original magnetite.

Goethite - 4% - Light to medium gray and with bluish tint where better polished, anisotropic but with polarization colors masked by reddish to brown internal reflections, variable hardness and perfection of polish. Present both as separate liberated grains and as partial rims on pyrite and chalcopyrite. Is an oxidation product of recent origin.

Jarosite - 2% - Either unpolished or with poor polish and medium gray color, very strong yellowish internal reflections. Occurs alone and in association with goethite as as recent oxidation product. In some instances borders pyrite.

Non-metallic gangue - 56%

*Note: Polished sections were prepared and examined for the head sample as received, for a heavy liquid concentrate of the sink fractions (S. G. greater than 2.89), and for a panned concentrate prepared from the head sample (two sections).

Arsenopyrite - -1% - White with slight creamy tint, moderately bireflectant, anisotropic and with blue to orange polarization colors, hard and is well polished. Scarce liberated grains and aggregates are scattered through sections. Shows somewhat stronger oxidation at grain margins than accompanying pyrite.
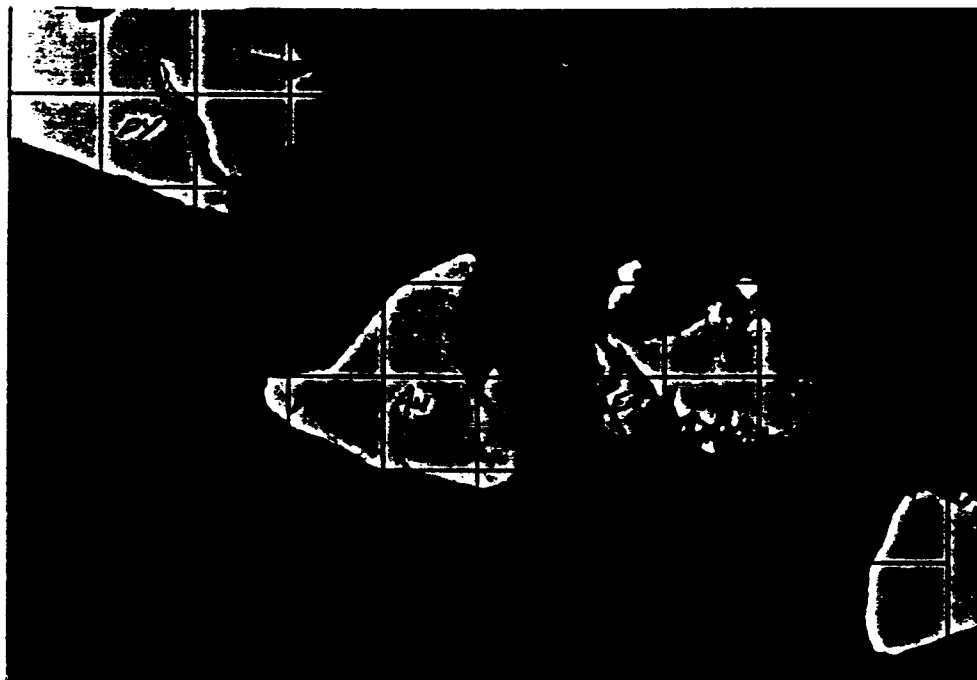
MLI-1103 (Panned 1). Polished section photomicrograph of native gold (Au) with one grain bordered by minor enargite and with associated fragments of pyrite. Plain light, X650. Each square of grid is 13 microns on an edge.
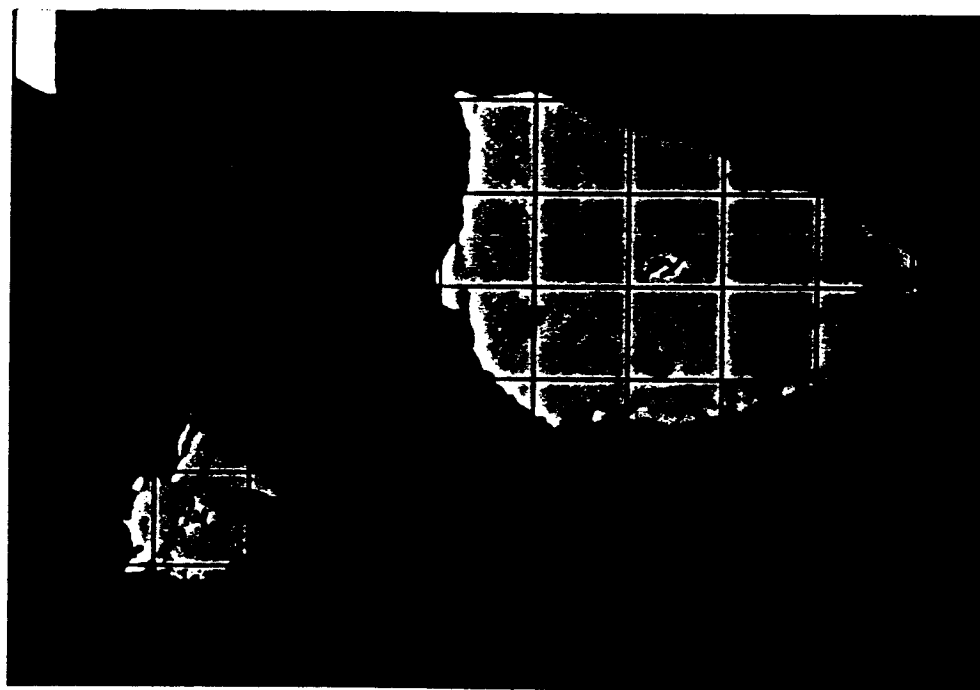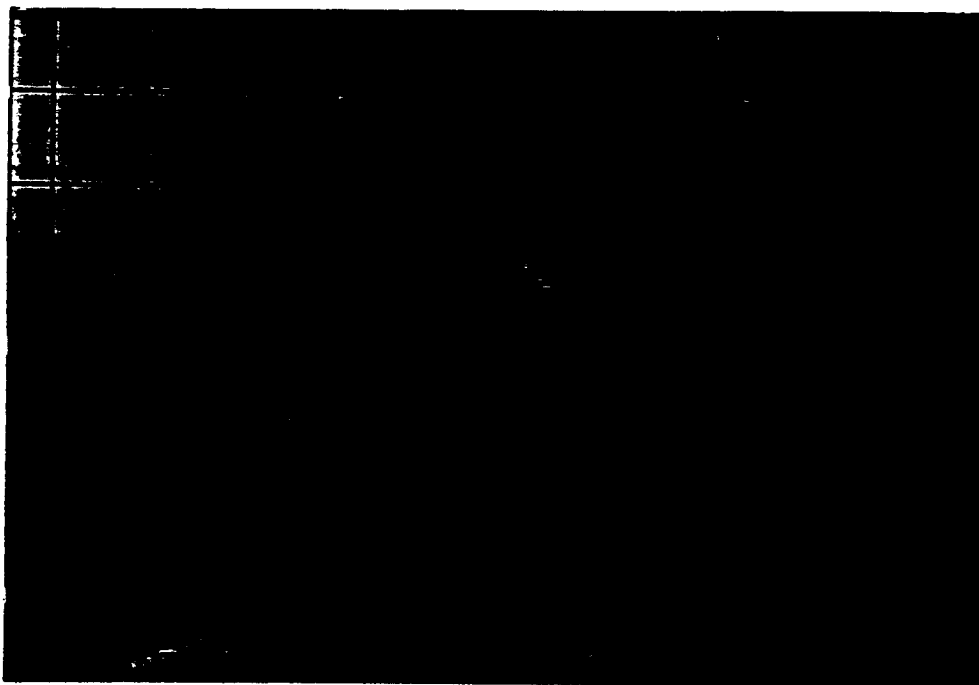

MLI-1103 (Panned 1). Polished section photomicrograph of liberated native gold with pyrite f agment. Plain light, X650. Each square of grid is 13 microns on an edge.
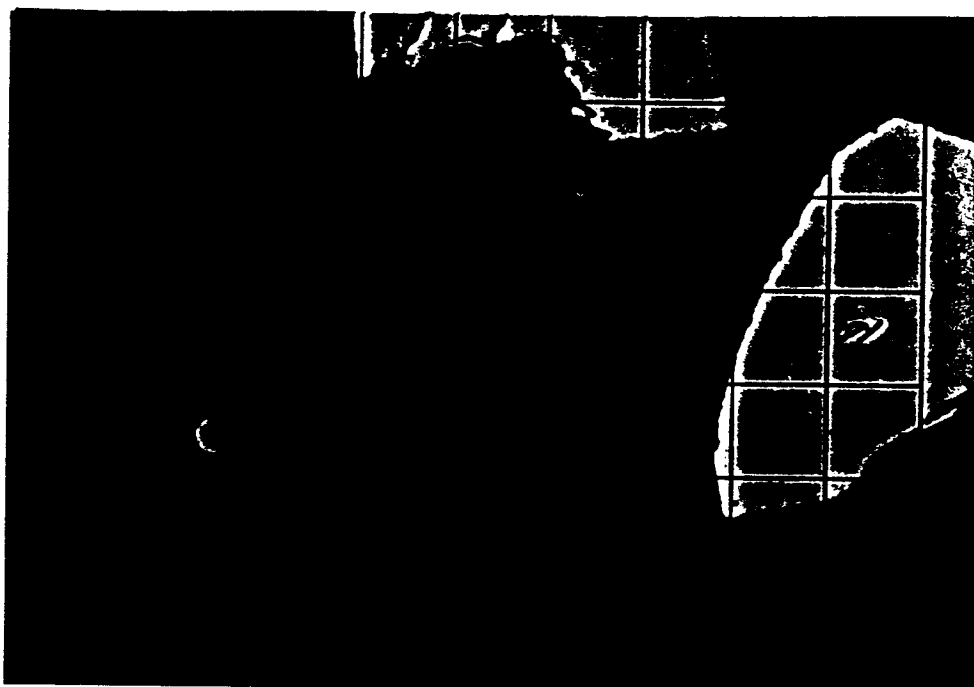
MLI-1103 (Panned 2). Polished section photomicrograph of libera-
ted native gold particle associated with fragments of pyrite,
chalcopyrite, and hematite. Plain light, X650. Each square of
gris is 13 microns on an edge.

MLI-1103 (Panned 2). Polished section photomicrograph showing
small locked particle of native gold in chalcopyrite, and
associated fragments of pyrite. Plain light, X650. Each
square of grid is 13 microns on an edge.

MLI-1103 (Panned 2). Polished section photomicrograph showing
small particle of native gold locked in silicate gangue that is
bordered by goethite and associated with pyrite. Plain light,
X650. Each square of grid is 13 microns on an edge.

MLI-1103 (Panned 2). Polished section photomicrograph of sphalerite
with microscopic inclusions of chalcopyrite and enclosed by
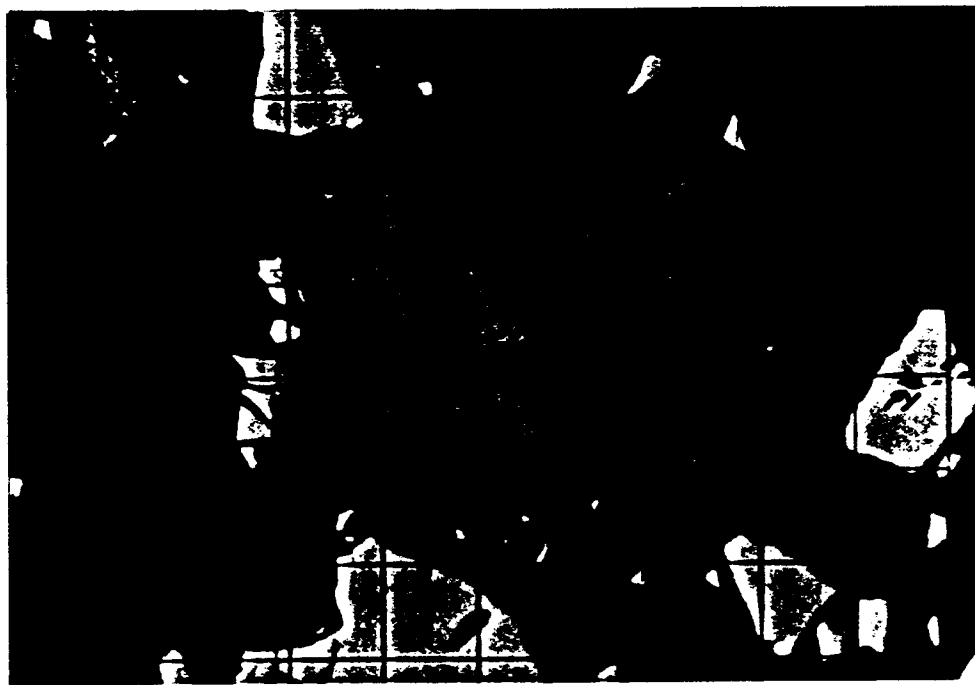pyrite. Plain light, X650. Each square of grid is 13 microns
on an edge.

MLI-1103 (Panned 2). Polished section photomicrograph of arseno-
pyrite aggregate associated with pyrite fragments - some of
which enclose sphalerite. Plain light, X260. Each square of
grid is 32 microns on an edge.
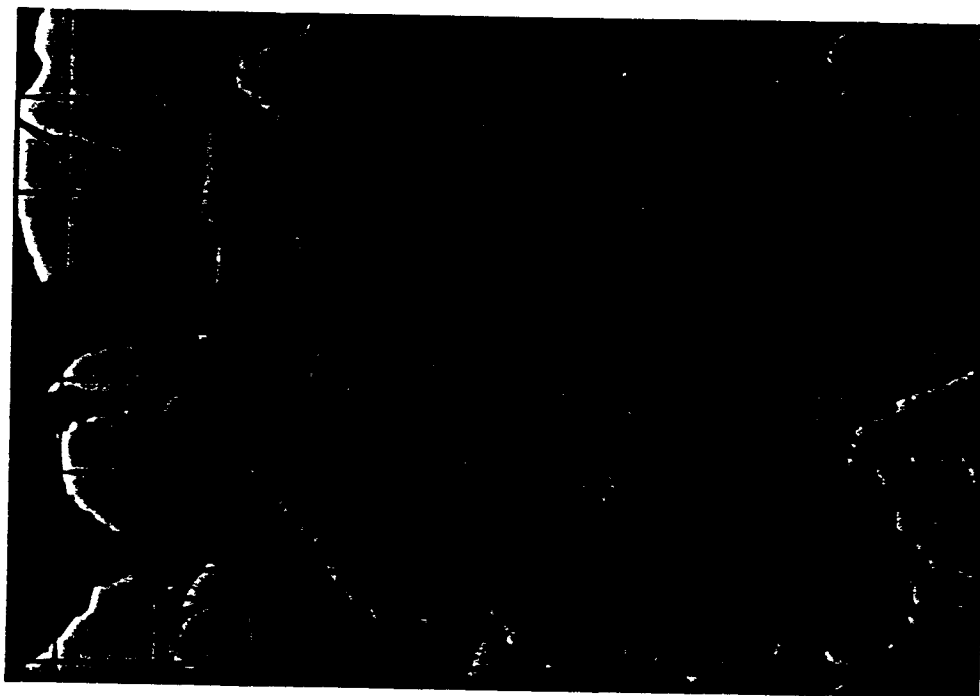
MLI-1103 (Panned 2). Polished section photomicrograph of chal-
copyrite forming composites with pyrite and associated with
separate pyrite grains. Plain light, X260. Each square of grid
is 32 microns on an edge.
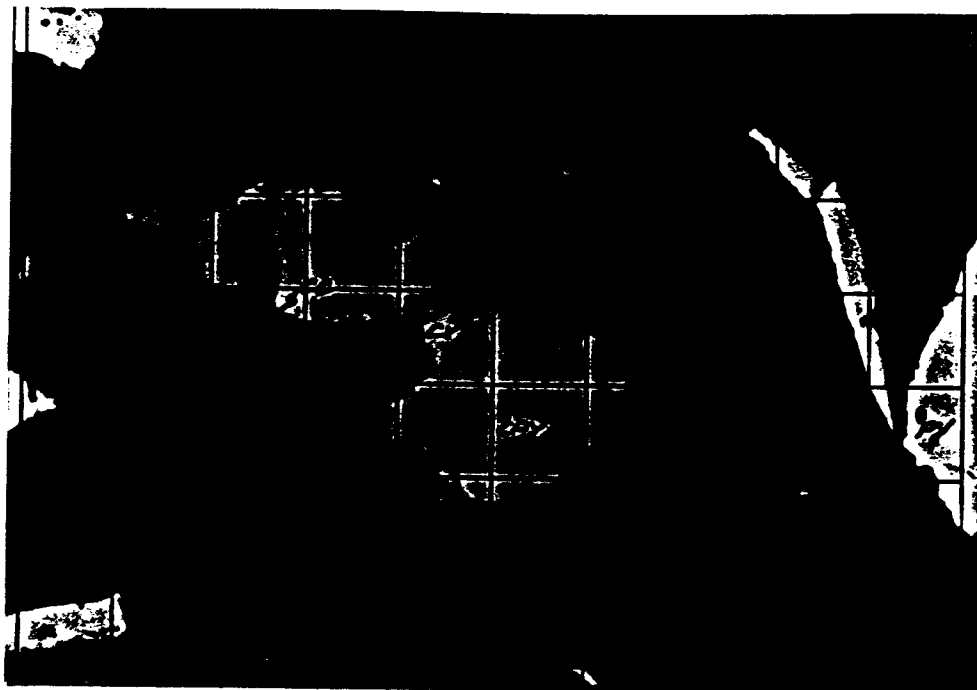
MLI-1103 (Heavies). Polished section photomicrograph of chal-
copyrite bordered by chalcocite and covellite adjacent to
jarosite fragment and associated with magnetite and pyrite. Plain
light, X260. Each square of grid is 32 microns on an edge.

MLI-1103 (Head Sample). Polished section photomicrograph of magne-
tite associated and intergrown with hematite. Adjacent frag-
ments are pyrite. Plain light, X650. Each square of grid is 13
microns on an edge.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION VIII
999 18th STREET - SUITE 500
DENVER, COLORADO 80202-2405

MAY 27 1988

Ref: 8HWM-ER

Mr. Andrew E. Nevin, Ph.D.,P.E., President
Granada Exploration Corporation
8 South Michigan Ave., Suite 501
Chicago, IL 60603

Dear Mr. Nevin:

In reviewing the information collected to date it appears that the USEPA Region VIII Emergency Response Branch will not initiate a removal action at the McClaren mine tailings site in Cooke City, Montana at this time. Continuing evaluations, however, will be conducted by the US Bureau of Reclamation as to the stability of those tailings.

If new information is made available which indicates that a response from our Branch is necessary, you and the current property owners will be notified.

Sincerely,

Donald J. Shosky, OSC
Emergency Response Branch

GRANADA
Exploration
Corporation

8 South Michigan Avenue, Chicago, Illinois 60603 (312) 236-8892

15909 Alder Place, White Rock, B.C., Canada V4A 5J1 (604) 531-1588

Chicago, May 31, 1988

Mr. Roger K. Andrews
Manager Asset Evaluation and Divestiture
BP Minerals America, Inc.
1515 Mineral Square
Salt Lake City, UT 84112

Dear Roger:

Re: McLaren Tailings Deposit
Section 25, T9S, R14E, Park County, Montana

Thank you for meeting with Earl Granger and me last
Wednesday. To recap our conversation -- I think each of us
has a much better understanding of each other's concerns.

We are planning to go ahead with reprocessing the McLaren
tailings and honoring your royalty commitment. In view of
your mining and reclamation experience we welcome the
opportunity to consult with you and seek out your advice on
various matters, particularly the final, permanent
reclamation of the tailings.

You have recommended final disposal about two miles to the
east and up 400 feet, on the other side of Colter Pass,
which is out of the Yellowstone Park drainage basin and in
the Clarks Fork drainage.

We also discussed the possibility that BP would contribute
the extra cost for such a first-class disposal job.

As I recall the physical setting at Colter Pass is adequate,
so we will look into the availability and cost of fee land
or Forest Service land there and the permitting and cost
aspects of transport and reclamation in the course of our
engineering. In due course we will advise. In the meantime
would you be so kind as to pursue this in principle so that
we can make a decision when the time comes?

Very truly yours,
GRANADA EXPLORATION CORPORATION

Andrew E. Nevin
President

cc: Earl W. Granger

CYANIDE HEAP LEACHING IN CALIFORNIA . . . .

By

KENNETH A. COLE
California Division of
Mines and Geology
Sacramento, California

and

ANN KIRKPATRICK
Department of Geology
University of Colorado
Boulder, Colorado

methods used,

plus

health and safety

aspects

The tremendous rise in gold prices in recent years initiated a new wave in interest in mining this metal in California. New areas of the State were prospected, and the older known gold-producing regions were re-examined to see if the price increase was enough to make it economical to recover gold from low-grade ore. Even waste rock and mill tailings from long-abandoned mines were assayed to see if they contained economic amounts of the metal. In many cases, the price jump alone would not have made reprocessing low-grade ores and wastes profitable if it were not for the introduction of a relatively simple, low-cost method of extracting the gold—cyanide heap leaching and activated carbon adsorption. This article is intended to provide a general introduction to the process and the chemistry/safety aspects of cyanide use for those who are not familiar with them.....*editor.*

INTRODUCTION

Heap leaching, using sulfuric acid or acid ferric sulfate solutions, has been used for processing copper ores for many years. The heap leach method, using cyanide (CN) solutions, has made it profitable recently to mine many large low-grade and small high-grade gold deposits, and to reprocess tailings and mine waste left from previous gold mining operations.

Heap leaching is a fairly simple technique that avoids many expensive and complicated steps. In 1974, the U.S. Bureau of Mines (USBM) estimated that heap leaching of suitable ores, coupled with extraction of the dissolved gold by carbon adsorption, lowered capital costs to 23 per cent of those of conventional processes, and lowered operating costs to 30 to 44 per cent of usual costs (Bhappu and others, 1974).

Gold recovery by the heap leaching method, however, is often lower, ranging from 50 to 70 per cent gold recovery as opposed to the 92 to 96 per cent recovery possible using other methods of gold recovery. In addition, the ore or tailings to be processed must be thoroughly tested to determine suitability to the cyanide heap leaching process. The nature of the chemical processing makes it necessary to adequately provide for environmental protection and health and safety concerns in the plan of operation. Reclamation and disposal of liquid and solid wastes after completion of the project must also be considered in the planning process.
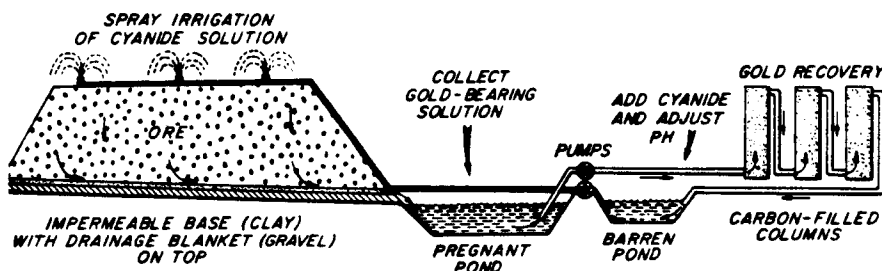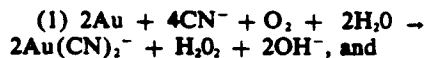

Figure 1. A simple heap leach setup. Methods for applying and collecting the solution can vary, but this is the basic leaching process.

HEAP LEACHING METHODOLOGY

In heap leaching operations, either crushed or run-of-mine gold ore is placed on specially constructed impermeable pads, and a dilute sodium cyanide (NaCN) solution is distributed into this heap by means of a spraying system or by ponding (Figure 1). The cyanide solution percolates through the heap, dissolving the gold according to the following reactions:

(1) $2Au + 4CN^- + O_2 + 2H_2O \rightarrow 2Au(CN)_2^- + H_2O_2 + 2OH^-$, and

(2) $4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)_2^- + 4OH^-$

(Heinen and others, 1978).

Application of the cyanide solution by spraying is more common in California than the ponding system. The spray application system increases the available dissolved oxygen needed in the reaction with the gold (equations 1 and 2 above). The ponding system of application is done by constructing berms on top of the heap to form one or more shallow ponds into which the cyanide solution is pumped.

In very cold climates, pipes and sprinklers used in spray application tend to freeze. Therefore, ponding has an advantage over spraying in cold regions in that the length of time that leaching can be done during the winter is extended (Beard, 1983). Ponding may have some limited applications within California, but spraying will probably continue to be the method that is commonly used.

At the bottom of the heap, the now gold-bearing solution is diverted by means of perforated pipes (Photo 1), a drainage blanket composed of gravel layered on top of the impermeable base, or gravel-filled channels to a "pregnant" pond, which is lined with compacted clay and/or plastic sheeting to prevent loss of the solution

Photo 1. Drainage collection pipes (in this case perforated plastic pipe) are placed between the ore and the impermeable pad to collect the gold-bearing cyanide solution. *All photos by Kenneth A. Cole.*
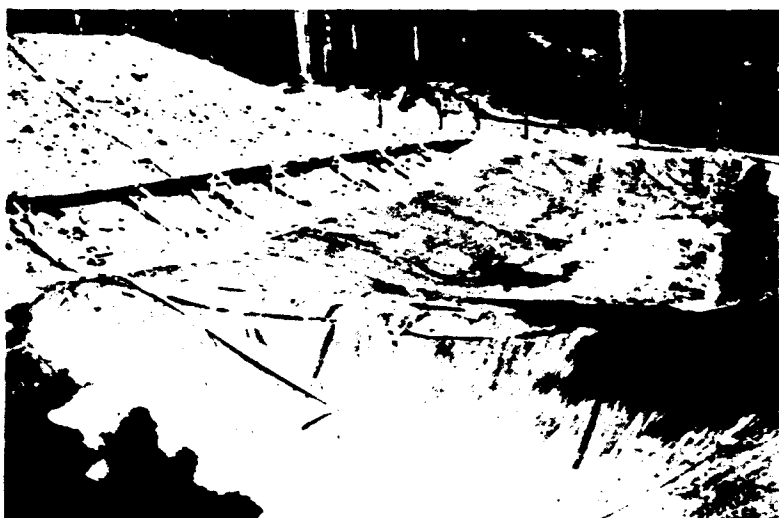

Photo 2. Both the "pregnant" and "barren" ponds are lined with plastic sheeting to prevent leakage at this small heap leach operation.

Photo 3. Pregnant cyanide solution is collected in pipes and fed into a cement sump, from which it is pumped to the recovery process site. A clay-lined emergency overflow and runoff collection basin surrounds the sump and insures that no cyanide overflows from the site as a result of heavy rainfall.

(Photos 2 and 3). The concentration of cyanide used in the leaching solution usually ranges from 0.5 to 2.0 pounds sodium cyanide (NaCN) per ton of solution, and the pH is kept between 10 and 11 (alkaline) to prevent the reaction of cyanide with hydrogen ions to produce toxic hydrogen cyanide (HCN). An adequate supply of dissolved oxygen is essential for efficient leaching of gold and silver. Aeration is provided through the sprinkling application of the cyanide solution, and available oxygen levels are enhanced by the loosely-packed construction of heaps.

One of the main advantages of the heap-leach recovery method is that it requires no special equipment to set up and, therefore, it has a relatively low capitol cost. Commonly, standard pumps and plastic sprinkler systems are used to apply the cyanide solution and to move the pregnant solution to the recovery columns.

In areas that are too steep or too wet to use a heap leach system, vat leaching can be used. However, this is a more complex method of leaching and requires a higher capital outlay for operations (Photos 4, 5, and 6). In a vat leaching system, crushed ore is placed in a container with cyanide solution and agitated by rotating vanes or by bubbling compressed air up through the mixture.

Heap leach pads must be made of material which will not allow escape of the cyanide solution, and must be constructed to drain the pregnant solution toward collectors or a pond. Material used to provide the impermeable base can be concrete, asphalt, clay, plastic sheeting, or a combination of these materials. Concrete and asphalt are most often used on pads which will be reused because they will hold up under the stresses of moving ore onto and off of the pad. Compacted clay, or clayey soils are the cheapest materials to use if they are available locally. If the local soils are not impermeable enough, plastic sheeting can be used in conjunction with the soil material. In areas, such as the desert, where clay soils are rare, plastic sheeting is commonly used.

Although small heaps usually result in less compaction, heap sizes range from 1000 tons to 50 million tons, with heights ranging from 4 to 100 feet. Generally, ore that has been crushed can be leached in smaller (1000 to 10,000 ton) heaps, requiring 7 to 30 days for thorough leaching. Crushing to ¾ to ¼ inch gives better exposure of the gold to the cyanide solution, yet still allows for good percolation. Although crushing is a rather expensive

process, the percentage of the gold recovered from the ore is higher and, therefore, crushing is generally a cost-effective method for increasing recovery rates.

Uncrushed, run-of-mine material is usually placed in larger heaps and requires longer leaching time—typically 60 to 90 days. Some very large heaps have been leached for years before recovery was no longer profitable. The tailings at Cortez and Gold Acres gold mines in Nevada together provided about 5 million tons of run-of-mine ore which were leached over a 7½-year period in 117,000 ton heaps that were stacked 20-feet high and had base dimensions of 350 x 450 feet. Recovery from these ores, containing values of gold from 0.050 ounces to 0.015 ounces per ton, averaged 50 to 65 per cent (Duncan and Smolik, 1977).

The gold values contained in the solution that collects in the pregnant pond are generally recovered by adsorption on activated carbon. The pregnant solution is pumped upward through a series of three to five columns (Photo 7) filled with granular activated carbon, which is manufactured from coconut shells. The activated carbon adsorbs the gold-cyanide complex by a mechanism which is not fully understood. The first, or lead, column adsorbs all the gold from the solution until it reaches a loading of about 20 ounces of gold per ton of carbon, after which some of the gold-bearing solution will continue through to succeeding columns, resulting in a solution essentially barren of gold after passing through the entire series of columns.

The barren solution is pumped to a storage and makeup tank or pond where sodium cyanide (NaCN) and caustic soda (NaOH) or lime (CaO) are added to bring the solution back up to the desired concentration and pH prior to reapplication to the leach pile. Cyanide consumption varies greatly with different ores. Typical amounts range from 0.1 to 0.4 pound NaCN per ton of leached ore. To maintain the pH of the solution in the desired range, 0.4 pound of caustic soda or 1.0 pound of lime per ton of ore is generally needed.

When the carbon in the lead column becomes fully loaded (200 to 400 ounces of gold per ton) it is removed, the remaining columns advanced, and a column with a fresh charge of charcoal placed at the end. The loaded carbon is placed in a stripping circuit where it is treated with a hot (about 200°F) caustic solution containing NaOH and some NaCN. This removes the gold from the carbon and puts it into solution in a form that can be deposited by electrolysis.

Photo 4. At this vat leaching operation, ore is fed in at the right, crushed within the building, placed into vats with NaCN solution to the left of the building, and goes back into the building to a carbon pulp recovery system. Tailings are piped to the disposal pond and cyanide-containing water is recycled back into the process.
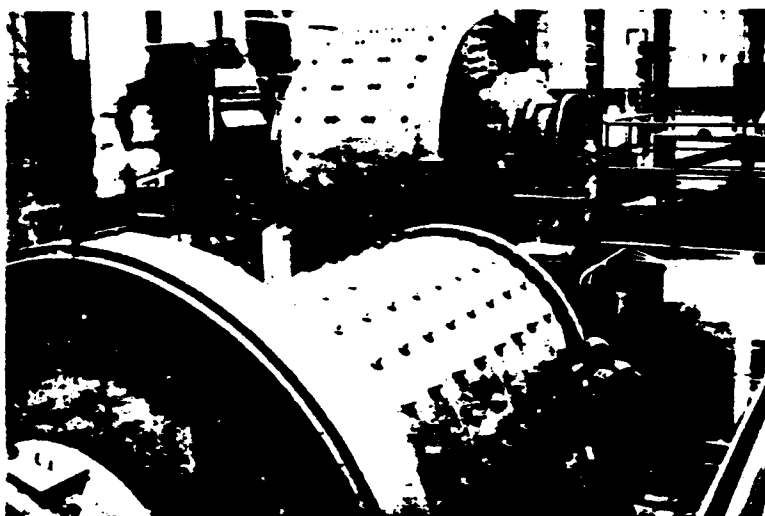

Photo 5. Rotary attrition mills grind the ore into sizes suitable for vat leaching. The ore must be small enough so that it can be agitated within the vats.

Photo 6. Steel vats used for leaching. A mixture of crushed ore and sodium cyanide solution is placed in the vat and agitated by compressed air which is fed into the bottom of the vat.

Development of this stripping method in 1952 has allowed carbon adsorption to replace precipitation on zinc dust (Zadra and others, 1952). Before this stripping technique became available, gold could only be removed from activated carbon by burning the carbon and then smelting the ashed residue. The costs involved in this were prohibitive for commercial application. Now, the carbon is washed, reactivated, acid treated, and reused after stripping.

Improved stripping rates can be accomplished with the addition of an alcohol, such as methanol or ethanol, to the stripping solution, or by performing the stripping step in a pressure vessel at about 52 pounds per square inch. Pressurized hot caustic stripping also reduces the amount of NaOH needed and eliminates the need for NaCN (Potter and Salisbury, 1974). Whatever method is used, the gold-bearing strip solution is sent to an electrolytic cell where the gold in solution is reduced to metallic gold and deposited on steel wool cathodes. The spent electrolyte is then recycled back to the carbon stripping circuit and the gold-plated steel wool is refined.

During the carbon adsorption process, it is necessary to regularly analyze the solution coming from the last column. This is commonly done using atomic absorption analysis. When the gold begins to be present in significant quantities, it indicates that it is time to advance the carbon columns and place a fresh charge in the last column. A regular check of gold values in the solution entering the columns and in the solution leaving the lead column can also be used to indicate when that column is fully loaded.

REQUIREMENTS FOR SUCCESSFUL HEAP LEACHING.

Before a full-scale heap leaching operation is implemented, metallurgical tests on the ore and laboratory and pilot heap leaching tests are conducted to determine whether the characteristics of the ore make it suitable for heap leaching, and whether it requires any special treatments. For example, silver is present in many gold ores and will also be dissolved by cyanide solution. Steps to separate the silver out of the solution can be added either before or after carbon adsorption. This is usually accomplished through the use of sodium sulfide (Na₂S) to precipitate silver sulfide (Ag₂S) out of the pregnant solution. The filtrate is then processed as usual by carbon adsorption

Photo 7. Lined steel columns, filled with activated charcoal made from coconut shells, are commonly used at heap leach operations to recover gold from the pregnant cyanide solution. The solution moves upward through each column.

to recover the gold. Silver sulfide can also be precipitated from the strip solution, and the filtrate is then electrolyzed to produce the gold (Heinen and others, 1978).

Heavy metal ions such as iron, copper, nickel, zinc, and manganese can retard the cyanidation of gold. Arsenic-containing minerals, such as realgar and orpiment, will react with the cyanide and inhibit the dissolution of gold. Sulfide minerals, such as pyrite, form acid when oxidized. This acid must be neutralized with larger quantities of lime or caustic soda. Carbonaceous materials, either occurring naturally in sedimentary deposits or from contaminants, such as charred mine timbers, will act as adsorbants for the dissolved gold. Other organic materials, such as oil and flotation reagents, will consume the dissolved oxygen that is necessary for the reaction of gold and cyanide (Heinen and others, 1978). Therefore, it is important to know the chemistry and mineralogy of the ore very well, and to design a process adopted to the characteristics of the ore. This will ensure maximum recovery of the gold and minimum consumption of reagents.

The ore to be leached must contain clean, very fine particles of native gold which can be readily dissolved by the cyanide solution. Most gold-bearing minerals, such as the tellurides sylvanite ([Au,Ag]Te₂) and calaverite (AuTe₂), are not readily soluble in cyanide solution. Native gold contained in simple oxide or

sulfide ores, as well as some placers, is generally the most suitable for cyanidation (Heinen and others, 1978). The host rock must be either porous to allow for good penetration of the cyanide solution, or contain gold along permeable fractures. Most gold ores that are currently being leached are non-porous rocks containing gold values along permeable fractures. Porous rocks that contain disseminated values as products of weathering are also suitable for cyanidation (Mining Engineering, 1979).

Because the heap must remain permeable to the cyanide solution, ores containing excessive amounts of fines (minus 100 mesh material) cannot be leached unless they are subjected to agglomeration techniques such as those recently developed by the USBM (McClelland and Eisle, 1982). For ores containing moderate amounts of fines, proper heap building techniques will prevent segregation of coarse and fine particles within the heap, and compaction and pulverization of the ores by trucks and equipment, which hinders thorough leaching. These techniques are described in detail in an article in the Mining Congress Journal (Chamberlin, 1981).

The USBM agglomeration technique allows clayey gold ores to be successfully heap leached, and also reduces leaching time and cyanide consumption when used on ores containing only moderate amounts of fines. Lime or Portland ce-

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ment, along with water or cyanide solution, is added to the ore and placed in a rotating agglomerator (Figure 2). This is followed by moist curing and results in a loose knit aggregate of fines and coarser particles. These aggregates are permeable, yet strong enough to hold together during leaching and mechanical handling (McClelland and Eisele, 1982). Agglomeration can also be accomplished to a lesser degree by wetting the ore prior to placement on the heap; the fines will become attached to the coarse particles as they roll and cascade during placement on the heaps.

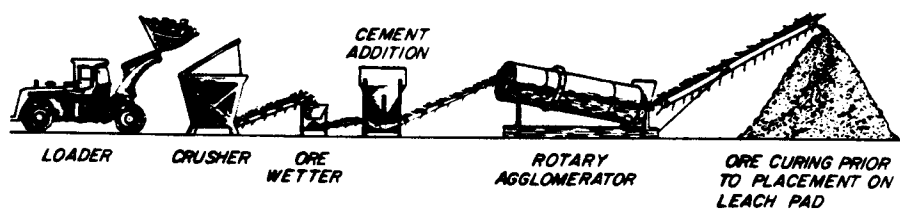LOADER   CRUSHER   ORE WETTER   ROTARY AGGLOMERATOR   ORE CURING PRIOR TO PLACEMENT ON LEACH PAD

Figure 2. A simple process for preparing fine-grained ore for leaching consists of crushing, wetting, addition of cement, agglomeration, and curing.

HEALTH, AND SAFETY CONCERNS

Cyanide is very toxic, but there have been few problems reported in California from its use in the mining industry. This can be attributed to proper training of mine personnel, respect for the toxicity of the cyanide by those using it, and strict controls on setup, transportation, and use of this chemical. The process should be a closed circuit, with all solutions being recycled. The greatest potential for harmful exposure to cyanide comes from improper handling and disposal, which could result in accidental spillage of the formation of poisonous HCN gas.

The acute effects of cyanide poisoning in humans and other mammals are well documented. The chronic effects of prolonged low-level exposure on environmental systems and the longevity of cyanide are not well known. For these reasons, most of the agencies involved in the permitting process and regulation of cyanide heap leaching operations in California have taken a conservative approach. Operating permits are required from local and state agencies, including county planning departments, Regional Water Quality Control Boards, and the California Occupational Safety and Health Administration (Cal/OSHA), regarding water and air quality, hazardous material transportation, storage and use, and occupational safety.

Cyanide Compounds

The cyanide compounds of most interest in heap leaching are the cyanide salts sodium cyanide (NaCN) and potassium cyanide (KCN), hydrogen cyanide (HCN), cyanate (OCN⁻), thiocyanate (SCN⁻), and the metal cyanide complexes. HCN is a liquid which boils at 25.7°C, and is, therefore, found at room temperatures in both the liquid and gas

phases. The cyanide salts dissociate in solution, resulting in potassium or sodium ions (K^+ or Na^+), cyanide ions (CN^-), and molecular hydrogen cyanide (HCN).

The cyanide ion and HCN are both toxic agents. Cyanate is formed from cyanide under oxidizing conditions and is less toxic than cyanide. Thiocyanates result from a reaction of cyanide with sulfur and are not toxic to humans. However, their presence in an acid environment results in the formation of HCN. Cyanide also reacts with many of the transition metals to form complexes such as ferrocyanide (Fe $[CN]_6^{4-}$), ferricyanide ($Fe[CN]_6^{3-}$), and many others. This ability of cyanide to complex with metals is responsible for both its usefulness in gold ore processing and for its toxicity.

Effects on Humans

When small amounts of cyanide are adsorbed into the blood, they are detoxified by reaction with thiosulfate to produce thiocyanate. When amounts larger than can be handled by this process are present in the blood, the cyanide complexes with the iron in the enzyme mithochondrial ferricytochrome oxidase. The activity of this enzyme, which is necessary for the production of oxygen, is then inhibited and results in anoxia. This lack of oxygen depresses the activity of the central nervous system, which, if severe enough, causes death.

Intake of cyanide can occur by inhalation of HCN gas or airborn salts; ingestion of salts; and absorption of liquid or gaseous forms through the skin. Inhalation of HCN at levels above 270 ppm are immediately fatal, whereas a level of 135 ppm is fatal after 30 minutes of exposure (Towill and others, 1978). Symptoms of acute poisoning are throat irritation, rapid pulse, headache, weakness, difficult breathing, numbness, collapse, and convulsions. Poisoning is treated by intravenous injection of sodium nitrate, followed by intravenous injection of thiosulfate.

Amyl nitrate and oxygen are administered as emergency measures until trained personnel are available. Other first aid measures include carrying the patient to fresh air, having the patient lie down, removing contaminated clothing, and flushing the skin with water if skin contact has occurred (National Institute for Occupational Safety and Health, 1976).

Research studies of the chronic effects of low-level exposure on workers in various cyanide-using industries were reviewed by the National Institute for Occupational Safety and Health in 1976. Long-term, low-level exposure was found to cause weakness, vertigo, nausea, headaches, dizziness, thyroid enlargement, and sulfur deficiency (National Institute for Occupational Safety and Health, 1976).

The acute effects that have been observed in humans and other mammals are similar, with each species demonstrating different thresholds of toxicity.

Effects on Fish

HCN is toxic to fish. Levels of free cyanide (HCN + CN⁻) as low as 0.02 mg/1 are lethal to some fish, with levels of 0.05 mg/1 and above lethal to many more species. The threshold level varies with duration of exposure, pH, amount of dissolved oxygen, and temperature (Doudoroff, 1976). Further investigation of the effect of the sub-lethal levels of cyanide exposure on fish is needed because 0.01 mg/1 of free cyanide can rapidly and lastingly impair the swimming ability of salmonoid fishes.

Effects on Plants

Cyanide inhibits respiration in most plants. The respiration of some plants, however, is insensitive to cyanide in varying degrees. In others, such as some legumes, cyanide can stimulate germination (Towill and others, 1978).

Cyanide in the Environment

In 1978 the EPA conducted a study to review the available literature on longevity of cyanide compounds in the environment (Towill and others, 1978). Certain species of micro-organisms are able to metabolize cyanide to ammonia (NH_3) and carbon dioxide (CO_2). These organisms are found in most soils; therefore, it is generally believed that low levels of cyanide will not persist in soils. It has also been reported that cyanide breaks down readily upon exposure to air. However, indications are that these processes are not operating in the desert-like and arid environments where most of the heap leaching operations in California are located. Soils in these locations are very thin and have little organic matter containing the necessary micro-organisms.

Both the California Regional Water Quality Control Board (RWQCB) in the Colorado River Basin Region and the USBM in Reno, Nevada, have recognized the need for research in this area. The RWQCB has found cyanide in abandoned heaps in southern California, and the USBM plans to study abandoned heaps in Nevada to determine the residual cyanide levels.

Water Quality and Liquid Waste Discharge

Water quality and liquid waste discharge controls are necessary in heap leach operations to minimize potential cyanide release to the environment as well as to control sedimentation and erosion problems stemming from the mining operation itself. The nine Regional Water Quality Conrol Boards in California have responsibility for monitoring and enforcing waste water discharge regulations. In areas with high precipitation, surface runoff is a major concern. Contamination of surface waters with cyanide, heavy metals, acid mine drainage, and suspended solids must be avoided to protect water used for drinking, irrigation, and watering of livestock, and to avoid adverse effects on fish, plants, and wildlife.

The processing solutions in cyanide heap leaching are usually recycled in a closed system because this method reduces operating costs and lessens the volume of solution which must be controlled. The CWQCB requires zero discharge from these operations. No water can be discharged during the operation without the special approval of the board. The facilities must be protected from flooding, inundation, and erosion result-

Photo 8. A new leach pad has been constructed using a sloping base, 18 inches thick, with a minimum of 30% clay. This pad will hold 600,000 tons of material at a 15-foot height.

ing from storms having a recurrence interval of 100 years or less. All possibly contaminated water must be retained on site (Photo 3). Berms and diversions to overflow ponds are usually constructed for this purpose.

Means of detoxifying cyanide solutions in the case of an emergency spill should always be available on site. Several neutralizing methods are known. Treatment with chlorine in the form of hypochlorite (OCl^-) is commonly used. The reaction that occurs forms carbon dioxide, sodium chloride, nitrogen, and water (Heinen and others, 1978). Cyanide can also be neutralized with chlorine gas or ozone. However, this method requires expensive equipment that would not be practical for the heap leach operator.

The solution resulting from neutralization with hypochlorite has a high salinity level. This has not yet been considered a problem in arid regions where the ground water is often naturally saline. High levels of heavy metals might also be contained in the solution and they would have to be precipitated out with lime or removed by other means before discharge would be permitted.

The hypochlorite neutralization process is also utilized in clean-up procedures at the closure of the operation. The cyanide solutions and processed tailings are neutralized and an analysis of cyanide concentration is submitted to the

RWQCB to determine neutralization acceptability before the solutions can be discharged. In drier areas solution ponds may be permitted to evaporate and any toxic residue that remains is shipped to an appropriate disposal site.

To prevent infiltration of solutions into the ground, leach pad and pond liners must meet permeability requirements of 1×10^{-6} cm/sec or slower. A leak detection system is desirable to detect leaking liners that can result from a wide variety of causes, including improper installation, the weight of the heaped ore, or differential settling. Many different materials have been used as pads and liners: compacted clay (Photo 10), asphalt, concrete, and plastics such as polyvinylchloride (PVC). Clay is preferable because of its natural ability to swell and repair any leaks that may develop. Whatever material is used, the RWQCB must approve design and construction of the pad before heap leaching can begin.

Solid Waste and Reclamation

Infiltration of waters into spent ore material may lead to problems if the ore is not neutralized properly after leaching. Depending upon the size of the operation, the amount of material processed, and the geographic characteristics of the site, the means of disposal of spent ore varies. The cyanide content of the material can be reduced to an acceptable level, as determined by the RWQCB, by washing with water or a dilute hypochlorite solution.

The tailings must then be stored in a location protected from surface runoff and from heavy rainfall. Leaving the heap in place on the pad usually affords this protection. This is done in many cases where the heap leach pad is not designed to be reusable and where suitable space is available to build more pads as needed. In some operations, spent ore is removed to either lined or unlined dump areas and the pad is reused. In another method, tailings are left in place, a liner is placed over them, and a new pad is constructed on top. Whatever method is used, the disposal site should be effectively isolated from surface flow and ground water aquifers.

Mine overburden must also be disposed of or used in ways to minimize erosion and problems of instability. Some overburden material may be used to level areas in preparation for leach pads, in construction of roads and diversion berms, or for backfill of mined areas with no future production value. Both overburden and tailings should be sloped at a ratio of 2 (horizontal) to 1 (vertical) or flatter to help prevent erosion and to enhance natural or planned revegetation efforts. Heap leaching results in fairly coarse tailings, so reclamation practices used with the fine tailings materials produced in vat and agitation leaching operations are not generally applicable.

Regrading of leach pads is done to help eliminate over-steep slopes, encourage natural drainage, and eliminate ponding (Jarrett and Kirby, 1978). The material can then be capped with three feet or more of soil to help prevent infiltration and provide a medium for seeding with the desired plant species. However, this is generally not possible in desert areas with little topsoil. In these cases, reclamation practices, such as grading to reduce slopes and enhance natural revegetation, may be the only practical means of restoring the area.

HANDLING AND STORAGE OF CYANIDE

Proper precautions must be taken in the handling of cyanide to eliminate the possibility of accidental poisoning and to minimize low levels of exposure that might result in adverse long-term effects. These precautions must be taken whenever unloading, opening, or emptying containers, handling or using cyanide, preparing solutions, cleaning tanks or equipment, or disposing of cyanide waste. CAL/OSHA has the responsibility for
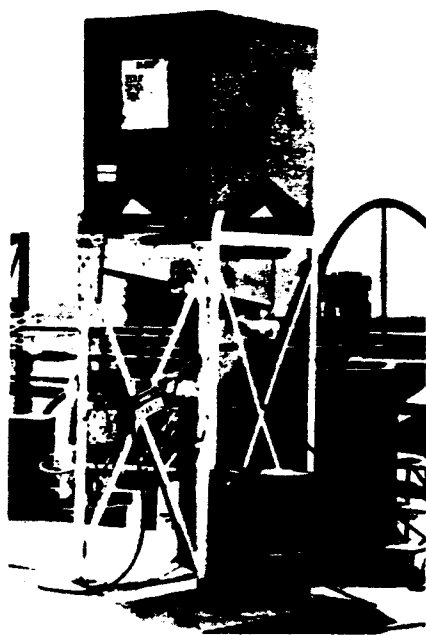

Photo 9. Cyanide briquettes are available in bins such as this one. These bins are handled with a fork lift and are reusable, thus eliminating many of the handling and disposal problems common to drum containers.

seeing that proper handling and storage techniques are followed.

Sodium cyanide used in the processing solution is transported in 200-pound drums as powder, granules, flakes, or one-ounce blocks. It can also be bought as a 30 per cent solution, or as briquettes which come in reusable bins (Photo 8). When transporting sodium cyanide, the containers must be properly labeled as to the materials and their hazards. The date, time, and route of transportation must be reported to the appropriate agencies, such as the Highway Patrol and the local county sheriff's office.

When storing cyanide, it is kept in sealed or tightly closed containers to protect it from moisture that may cause HCN to be formed. Empty containers can not be disposed of on site. Unwashed containers must be disposed of at a Class I disposal site; triple-rinsed containers can be disposed of in Class II-I disposal sites.

When handling cyanide in either the solid or liquid form, protective clothing and gloves should be worn. There should be no eating, drinking, or smoking in the areas where cyanide is present. Workers should be thoroughly informed of the hazards of exposure to cyanide, first aid

procedures, the need for protective clothing, and the proper procedures in the event of a spill.

Spills of dry cyanide should be swept up and the area thoroughly washed with alkaline water. Liquid spills should be neutralized with hypochlorite. All spills should be kept from coming into contact with acidic solutions (which may be present in sewer drains) as this will cause HCN gas to be formed. Exposure to CO_2 and water will also cause lesser amounts of HCN gas to be formed. Signs should be posted in the workplace giving first aid and emergency instructions, and first aid kits containing amyl nitrate ampules, physician treatment kits, and emergency washing facilities (Photo 9) should be on site (National Institute for Occupational Safety and Health, 1976).

Inhalation of gases formed during leaching is generally not a problem because the leaching is conducted outdoors. Studies by the Mining Enforcement and Safety Administration show that the HCN concentration in the air near heaps
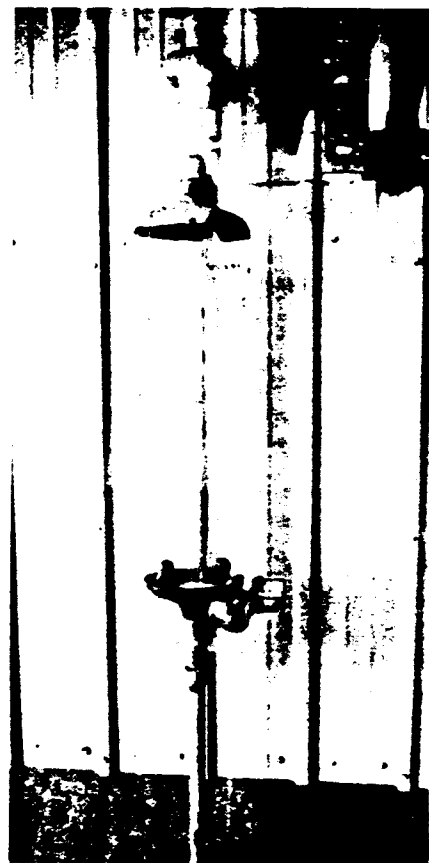

Photo 10. Wherever cyanide compounds are handled or used, emergency washing stations should be installed.

is generally 2.0 to 3.0 ppm, while the CAL/OSHA recommended limit is 4.7 ppm for both HCN gas and NaCN dust (National Institute for Occupational Safety and Health, 1976). If any processing steps occur indoors, those areas must be properly vented to keep the levels of HCN gas and airborne salts below this limit.

SUMMARY

Most people are aware of the toxicity of cyanide, but few are familiar with its other characteristics or with the widespread industrial use of cyanides. Leaching with cyanide solutions has been carried out for many years with a very low incidence of accidents. This may be in part attributed to the relatively simple nature of leaching operations, in part to the dependence of the economic success of leaching operations on controlling the gold-carrying solution, and in a large part on the caution with which it handled.

Free cyanide is rapidly destroyed under normal atmospheric conditions, does not accumulate in organisms, and can be metabolized in small quantities with no residual effects in humans. If the cyanide is properly controlled during transportation and use, the mining operation that uses the heap leaching method can have fewer adverse environmental impacts than one employing conventional methods for gold recovery.

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